FINAL VERSION

Cover Drive and Lock Ring Mechanisms for Genesis

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Abstract

The Genesis payload canister will return solar wind samples to Earth. The canister contains four mechanism assemblies: the Cover Drive Mechanism, the Lock Ring Mechanism, the Array Deployment Mechanism, and the Array Latch Mechanism. The Cover Drive and Lock Ring Mechanisms are described in detail while the other two mechanisms are briefly summarized. The Engineering Model canister has been designed, built, tested, and delivered to the spacecraft. The Flight Model is currently being built with delivery to the spacecraft scheduled for mid July 2000. Launch is scheduled for January 2001.

Introduction

The Genesis mission will place a spacecraft outside the Earth's magnetosphere and expose ultra-pure materials to the solar wind for about 23 months. Figures 1 and 2 show the stowed payload canister integrated with the Sample Return Capsule (SRC) and the spacecraft. The Electron Monitor and the Ion Monitor are sensor assemblies that provide data about the electrons, protons, and alpha particles in the solar wind as a function of time. These data are input to the science algorithm, which controls the specifics of the solar wind collection. The embedded solar wind samples will be returned to the Earth within the payload canister, safely contained within the SRC for reentry. The SRC will be retrieved by mid-air recovery.

The canister is rich with mechanisms, containing four distinct assemblies: the Cover Drive Mechanism, the Lock Ring Mechanism, the Array Deployment Mechanism (ADM), and the Array Latch Mechanism. Two key components, the Cover Drive and Lock Ring Mechanisms are the focus of this paper. These two mechanisms provide straightforward functions: a launch latch and the means to open and close the canister cover, but their requirements and design are linked together creating a much more challenging problem.

Figures 3 and 4 show the integrated canister in both the closed and open configurations. The Cover Drive Mechanism and Lock Ring Drive Mechanism are visible on opposite ends of the canister. The Lock Ring Assembly is located around the perimeter of the canister between the cover and base flanges. Solar wind is captured with both the Concentrator and the hexagonal collectors that fill the arrays. The ADM (not visible in the figures) is a stepper motor drive with separate motors used to position each of the four deployable arrays in the base. The Array Latch Mechanism secures the stowed arrays for launch and reentry.

Lock Ring Mechanism

<u>Requirements</u>

The Lock Ring Mechanism consists of the Lock Ring Assembly and the Lock Ring Drive Mechanism. Along with the Canister Seal, this mechanism's purpose in the canister assembly is: to provide a launch latch for the canister cover to sustain launch, reentry, and recovery loads; to prevent contamination of the canister interior; and to produce a push-off force to separate the seal interface. An additional requirement is that the mechanism must be capable of performing a functional test to verify the flight electrical interfaces and actuator operation without opening the canister to avoid contamination of the interior of the flight unit.

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Description

The Lock Ring Assembly consists of a 7075-T73 aluminum ring (81.28 cm (32 in) in diameter) with twenty-four ½-inch-diameter track roller pairs equally spaced around the ring perimeter. The entire Lock Ring Assembly is seen in Figures 3 and 4 but a more detailed view is available in Figures 5a and 5b and the section views in Figures 6a and 6b. This basic configuration was inspired by the Shuttle Get-Away Special (GAS) design. The upper row of track rollers is mounted on twenty-four bending beam flexures that create a clamping force on the joint by rolling up ramps to the locked position. The clamping force compresses the seal and preloads the joint against launch/reentry forces so that metal-to-metal contact is maintained. The two bending beam flexures located nearest the Array Latch Mechanism are stiffer in order to react the additional inertial loads of the arrays. Radial bearings at twelve locations around the ring provide both radial alignment capability and radial load capacity. The track rollers in the upper row are tilted downward in their unloaded state, 1° for the regular flexures and 2° for the stiff flexures. As load is applied to the track rollers, the bending beam flexures both deflect and rotate because the track rollers are cantilevered from these flexures. Tilting the track rollers in their unloaded state ensures that in the fully loaded state, the track rollers are loaded in the center of their outer bearing race.

Obtaining and maintaining the metal-to-metal contact during launch and reentry was the biggest challenge for the canister structure and lock ring system. This feature is a distinct difference between the Genesis payload design and the Shuttle GAS and it is an important difference because of the Genesis need for extreme contamination control. The initial design for the cover and the base consisted of simple cylinders with flanges at the separable interface. A first order load analysis that simplified the base as a rigid structure was used to estimate the clamping force required from the Lock Ring. In this simplified analysis, mass acceleration of the cover in the direction normal to the interface was reacted by the Lock Ring clamping force while in-plane mass accelerations were reacted with the shear pins installed in the base flange. The underlying assumption in this simplified analysis is that minimal coupling exists between the load directions. The inadequacy of this assumption quickly became apparent in a more detailed load analysis. Loads are transferred from the SRC to the canister base through a set of three bipods, which are partially visible in Figure 3. Because of this configuration, loads reacted into the base from the SRC create in-plane deflections of the base. In turn, the relatively stiff cover deflects in the same way as the base, absorbing quite a bit of the load and causing the tensile load at the separable interface to increase dramatically. The cover and the base were redesigned to bring the tensile loads at the interface back to an acceptable range. A kick ring was added to the base and a cover flexure was added to the cover (Figures 6a and 6b). The kick ring stiffens the base, which reduces the in-plane deflections while the cover flexure softens the cover, which reduces the transfer of load from the base to the cover. The bending beam flexures in the lock ring were redesigned to accommodate a small increase in load.

Two push-off blocks are attached to the cover on each side of the Lock Ring Drive Mechanism. Together the push-off blocks provide a separation force, if needed, at the seal interface when the ring unlocks. Push-off reaction pads, mounted on the kick ring, capture the Lock Ring Assembly when unlocked and act in conjunction with the push-off and shorting blocks to create the seal separation. The Canister Seal consists of silicone in a Gask-O-Seal configuration incorporated in an aluminum retainer. The top surface of the seal retainer is hard anodized and the bottom surface of the mating cover flange is covered with Magnaplate, a nickel-based coating, to form the separable interface. A thin layer of Braycote grease covers the seal. Tests were performed using seal samples under prolonged clamping and exposed to representative temperature, vacuum and radiation environments. There has been no sign of stiction with these material combinations. In addition, there was no evidence of stiction at this interface during the functional testing of the Engineering Model canister.

Figure 7 depicts the operation of the Lock Ring Assembly. In the unlocked position, there is no load on the track roller pair. The upper track roller is tilted downward and the lower track roller is captured between the lower bearing pad and the push-off reaction pad. The push-off reaction pads occur only in four places and they keep the Lock Ring in place when the mechanism is unlocked. During locking, the first track roller contact with the ramp occurs about a third of the way through the travel. At this point the seal is not compressed and the lower track roller is still captured between the lower bearing pad and the push-off reaction pad. Notice that to get to the first ramp contact, the upper roller had to hit the push-off block. As the mechanism turns past first ramp contact, the flexures start to deflect and rotate, applying a force to compress the seal. When the seal is fully compressed, the lower track roller is no longer over the push-off reaction pad. Just past this point the ramp changes slope to a smaller ramp angle. In the initial design, the ramp inflection and the fully compressed seal both occurred at the same position. This was done to minimize the torque required to drive the track rollers up the ramps. When the flexures stiffened during the design iteration that resulted in the kick ring and cover flexure, seal compression occurred slightly earlier. The ramps were not redesigned since enough torque margin remained in the Lock Ring Drive Mechanism. Near the end of travel the ramp changes to a flat. In the locked position at 12.5°, the regular flexures have deflected 0.96 mm (.038 in) and rotated through 1° to the horizontal position while the 2 stiff flexures have deflected 0.43 mm (.017 in) and rotated 2° also to horizontal. Total preload on the separable interface is 21,218 N (4770 lbf).

During unlocking, the same force/deflection profile is followed in reverse. If there is stiction between the cover flange and the seal, the upper track rollers act on the two push-off blocks opposite the hinge line to create a significant prying force at each push-off block. The shorting block stiffens the load path so that the action of the push-off force does not cause the bending beam flexures to bend in the opposite direction, shortening the push-off stroke. The push-off stroke was measured during characterization of the Engineering Model canister. The Lock Ring Mechanism was stopped when the upper track rollers were at the center of the push-off blocks. With no sign of stiction present, the gap at the separable interface between the two push-off blocks was three times the seal crown height. The gap tapered off to 1.5 times the seal crown height at the two points halfway between the Lock Ring Drive Mechanism and the Cover Drive Mechanism. With stiction present, some of this push-off stroke would be taken up by deflection in the integral cover flexure.

In the Lock Ring Mechanism, there are design tradeoffs between the ramp profile, the torque required to lock the ring, and the lock ring flexure design. An additional tradeoff exists between the capture range of the device and the push-off stroke. In order to contact the push-off block during unlocking, the upper track roller must also contact the block during locking. This initially raises the cover a small amount during locking and reduces the capture range.

The Lock Ring Drive Mechanism (Figures 8a, 8b, and 9) provides torque to lock and unlock the Lock Ring and to operate the Array Latch Mechanism. The mechanism consists of a dual-wound, electronically-commutated gearmotor with redundant Hall effect rotor position sensors and drive electronics. The gearmotor drives into a pinion and sector geartrain mounted on the Lock Ring. The gear ratio of the pinion and sector is 22.3:1. The gearing in the motor is a four stage planetary with an overall ratio of 2160:1. Radial loads from the gear mesh are reacted into the track roller and bearing assembly of the mechanism rather than directly into the Lock Ring to minimize Lock Ring deflection and maintain the correct gear mesh. The mechanism operates by driving into hard stops at the end of travel in each direction until a timeout occurs. Microswitches provide confirmation that the mechanism arrived at the hard stop. The mechanism operates at a constant speed of about 0.0524 rad/s (0.5 rpm) due to speed control in the drive electronics. Traveling between hard stops takes about 98 seconds during unlocking and 100 seconds during locking.

The "No Open" functional test is performed to confirm the mechanism operation without opening the canister cover. During the "No Open" functional test, the cover and base are clamped together with external clamps to maintain the seal and the push-off blocks are removed. The Lock Ring Mechanism can then be operated over its full range to verify proper function.

<u>Testing</u>

Figure 10 shows the results of a functional test of the Lock Ring Mechanism at room temperature during both locking and unlocking. The predicted locking torque is also shown for comparison. The peak required torque of 16.5 N•m (146.4 in•lbf) occurs at 6.2° during locking. The shape of the actual locking torque curve generally follows the predicted locking torque curve between the first roller contact and fully loaded positions. The peak of the actual curve is lower than predicted because worst case friction assumptions were used for the prediction. The actual curve is more rounded because the prediction assumed that all the track rollers reach the predicted conditions at exactly the same time. The variation causes an averaging effect. The same phenomenon is observed at the end of travel. In order to create the desired clamping force at each bending beam flexure in the locked position, the height of the flat part of each ramp is individually adjusted to nullify the tolerance stackup accumulated by the cover and base flanges, the seal retainer, and the lower bearing pad. The locking torque starts to drop off at about 10° as some of the track rollers reach the flat part of the ramp much earlier than the others do. The unlocking torque is lower than the locking torque as the clamping force on the ramps tends to help during unlocking.

During all functional testing, the highest torque required by the mechanism was 22.04 N•m (195 in•lbf) during cold operation. During dyno testing of the motors the lowest gearmotor stall value observed was 73.45 N•m (650 in•lbf) resulting in a minimum torque safety factor of 3.3.

Cover Drive Mechanism

Requirements

The Cover Drive Mechanism provides torque to open and close the canister cover. As with the Lock Ring Mechanism, the Cover Drive Mechanism must operate in 1g and must be capable of performing a functional test to verify the flight electrical interfaces and actuator operation without opening the canister (the "No Open" functional test).

Description

The Cover Drive Mechanism is illustrated in Figures 11a, 11b, and 12. The same gearmotor and drive electronics are used in both the Lock Ring Drive Mechanism and the Cover Drive Mechanism but in this case the gearmotor drives directly at the cover hinge axis using the hex drive on the gearmotor instead of the pinion gear. The drive hub turns on a lightly loaded, spring-preloaded bearing pair. The preload is not sensitive to thermal changes because of the spring preload. The hinge axis is located at the seal crown height (i.e. above the metal-to-metal interface between the canister cover flange and the seal retainer mounted on the canister base flange). Positioning the hinge axis at the seal crown height instead of at the seal retainer surface minimizes the capture range needed from the Lock Ring Mechanism, however it also requires cover translation to seal the canister when the lock ring engages. Relatively stiff cover arm flexures, integrally machined into the cover arms, permit this cover translation. The design of the cover arm flexures was a particular challenge. The torque tube is needed to stiffen the torsional load path between the two arms because only one arm is driven by the gearmotor. However, the torque tube occupies a great deal of space in the mechanism leaving little room for flexures. In order to find room for the flexures, the cover arm attachment points were changed from a more straightforward location to the more unorthodox attachment scheme shown in the figures.

During normal operation of this mechanism, the gearmotor turns the drive hub, which is attached by four fasteners to the drive arm. The mechanism moves until the hard stop arm integral to the drive hub hits either the open or closed hard stop. A timeout turns off the gearmotor command and microswitches provide confirmation that the mechanism reached a hard stop. During the "No Open" functional test, the four fasteners that hold the drive arm to the drive hub are removed. Now when the gearmotor rotates the drive hub through the hex drive, the motion occurs at the Cover Drive coupling interface (Figure 12) instead of opening and closing the canister cover. The hard stop arm on the drive hub is able to move through the full 180° of travel between the two hard stops so both the gearmotor and the microswitch operation can be verified without opening the canister cover. The mating surfaces at the Cover Drive coupling interface are treated to prevent galling and to produce low friction. The faying surfaces of the 7075-T73 aluminum arm are hard anodized and the corresponding surfaces on the 15-5 steel drive hub are covered with a dry film lubricant, Lub-Lok 4306.

Testing

Figure 13 shows the opening of the Cover Drive Mechanism under three conditions: actual in 1g, predicted in 0g, and actual during a "No Open" functional test. During opening in 1g, the maximum torque of 57 N•m (504 in•lbf) is required at the beginning of travel, decreasing in the expected sinusoidal shape as the center-of-gravity of the canister cover approaches the 90° position. Once past this position, gravity assists the gearmotor in opening the cover. The weight of the cover backdrives the gearbox, which counteracts the motor losses in the gearbox, and causes the electronics to provide less current to turn the gearmotor. This shows up in the torque trace as a negative output torque at the mechanism. The drive electronics are a unipolar drive, only controlling the gearmotor to produce torque in the commanded direction, in this case, the open direction. When the gravity-assist fully cancels the gearmotor losses, the speed increases beyond the electronics speed control value of about 0.0524 rad/s (0.5 rpm). The electronics commands no more torque and the mechanism increases in speed until it coasts into the hard stop. This is the flat part of the curve at -13 N•m (-115 in•lbf) near the end of travel. Once at the hard stop, the electronics commands the gearmotor to stall against the hard stop. It takes 49 seconds for the cover to open in 1g, which is faster than 0g operation because of the gravity-assist. The "No Open" functional test duration of 65 seconds is indicative of the on-orbit performance of the mechanism. Turning the Cover Drive coupling interface requires only about 7 N•m (62 in•lbf). The predicted opening torque in 0g is very low with a peak of 3.8 N•m (33.6 in•lbf) occurring in the first second of travel. This peak represents a worst case estimate of the Cover Drive Mechanism torque required to disengage the Array Latch crank from the Array Latch actuator block. The 0g operation of the mechanism has a torque factor of safety in excess of 19.

Array Latch Mechanism

In the stowed position, the four deployable arrays are supported at three points: the ADM, the fixed saddle, and the moving saddle. These support points (visible in Figure 4) are approximately equally spaced. Both the ADM and the fixed saddle are mounted on the inside of the canister base. The moving saddle is part of the Array Latch Mechanism, which is mounted on the canister cover. This attachment scheme creates the additional inertial load that makes the two stiffer bending beam flexures on the Lock Ring Mechanism necessary. The force necessary to operate the Array Latch Mechanism is provided by the Lock Ring Drive Mechanism through the action of the Array Latch actuator block on the crank. When the Lock Ring unlocks, the Array Latch unlatches and the canister cover is free to open. The actuator block is mounted on the Lock Ring and is therefore attached to the canister base. When the canister cover opens, the crank separates from the actuator block. This separation is mission critical. The Array Latch Mechanism must maintain its position when disengaged from the actuator block so that the crank is able to reengage the actuator block when the cover closes. As the crank moves, it drives a camshaft that controls the motion of the mechanism. A cam follower link is part of the four bar linkage that positions the moving saddle. The moving saddle engages slots in each of the four arrays by rotating through a limited angle on a simple pivot. The moving saddle on its simple pivot and a portion of the Array Latch housing are the only parts of the mechanism exposed to the inside of the canister with its extreme cleanliness requirements. The linkage that articulates the moving saddle operates through a flexible metal bellows that seals off the rest of the mechanism from the canister interior. The bellows also acts as a spring to hold the cam follower link in the cam detent when the Array Latch Mechanism is in the unlatched position. Very little of the Lock Ring Drive Mechanism's torque capability is used to actuate the Array Latch Mechanism. The peak load occurs at the very beginning of latching when the cam follower link is coming out of the cam detent. This corresponds to the beginning of locking when the torque required to turn the Lock Ring Mechanism is low.

ADM

The function of the ADM is to independently move each of the four deployable arrays between three locations: stowed, unshaded, and deployed. The latter two positions are used for solar wind collection and are 104° and 256° respectively from the stowed position. As with all the other Genesis mechanisms, the ADM is able to perform in 1g. The ADM consists of four coaxial drive tubes with flanges each mechanically connected to an individual array and supported on bearings. Each of the tubes is separately driven by an independent mechanism consisting of a 30° stepper motor with a three stage planetary gearbox, a pinion and spur gear drive train, and three microswitches for position telemetry. The ADM joins to the Canister via a bolt circle and o-ring seal. The ADM is lubricated with Braycote grease. The Genesis contamination control requirements are met by venting the interior of the mechanism through the floor of the canister. Rotary teflon seals prevent ADM outgassing into the interior of the canister.

Additional Design Considerations

The cleanliness of the delivered Flight Model integrated canister and in particular the interior of the canister is critical to the success of the Genesis mission. All the material returned in the arrays and the concentrator will be assumed to be solar wind so it is essential to keep contaminants from these ultra-pure materials. This is accomplished in a variety of ways. The materials in the canister design, particularly within the canister interior were chosen to minimize contamination of the solar wind samples and to maximize the ability to clean the payload hardware. The only opening in the closed canister is through the filter. The processing sequence of the canister is set up to keep the canister interior as clean as needed.

The Flight Model integrated canister is built at JPL and undergoes both vibration and thermal/vacuum qualification testing at this subsystem level. The canister then goes to Johnson Space Center (JSC) where it is partially disassembled and rigorously precision cleaned. The canister is reassembled in a Class 10 cleanroom. In Figure 14, the Cover Drive Mechanism is reinstalled after cleaning at JSC. Personnel perform the operation in a Class 10 cleanroom while outfitted in Dryden suits with HEPA filters. The hexagonal collectors are replaced with new pristine collectors. The canister is closed and locked in the ultra cleanroom at JSC and it is never opened again until it is in space. The canister is purged with clean, dry nitrogen from this point until launch fairing closeout. Integration within the SRC and the spacecraft takes place outside the ultra clean environment so it is impossible to open the canister without contaminating the collectors and the concentrator. The only way to verify the flight electrical interface between the spacecraft and the integrated canister is with the "No Open" functional tests.

Conclusions

Both mechanisms have interesting design challenges of their own. In the Lock Ring Mechanism, the ramp profile, the torque required for locking the ring, and the lock ring flexure designs all interact. Key to the design of this type of mechanism is the incorporation and control of the structural compliance (flexures) that allows a controlled preload in the metal-to-metal separable seal surface. The capture range of the Lock Ring Mechanism and its push-off stroke are also directly related. In the Cover Drive Mechanism, incorporating both the torque tube and the cover arm flexures posed a particular problem. However, the most interesting aspect of all is the coupling between the two mechanisms and between the mechanisms and the structure. The canister seal is needed because of the extreme contamination requirements in the canister interior. The existence of the seal forces the Cover Drive Mechanism hinge line to the top of the seal crown height to maximize the actual capture range of the Lock Ring Mechanism. This hinge line location makes the cover arm flexures necessary. The force needed to deflect the cover arm flexures adds directly to the preload required from the Lock Ring Mechanism when clamping the seal interface. The canister cover and base structure design directly influences the loads transmitted across the seal interface thereby affecting the Lock Ring Mechanism design. Parameter changes in one area during detailed design iterations quickly rippled through all the payload design interactions. All these interactions added complexity to the overall design problem.

Status

The Engineering Model canister has been designed, built, tested, and integrated into the SRC. System level testing is in progress. The Flight Model canister will be built and tested during the year 2000 with delivery to the spacecraft scheduled for mid July 2000. Launch is scheduled for January 2001.

Acknowledgements

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The spacecraft and the SRC are designed and built by Lockheed Martin Astronautics in Denver. The Concentrator, Electron Monitor, and Ion Monitor are provided by Los Alamos National Laboratory. The ADM was delivered by American Technology Consortium and CDA Astro Intercorp furnished the gearmotors.

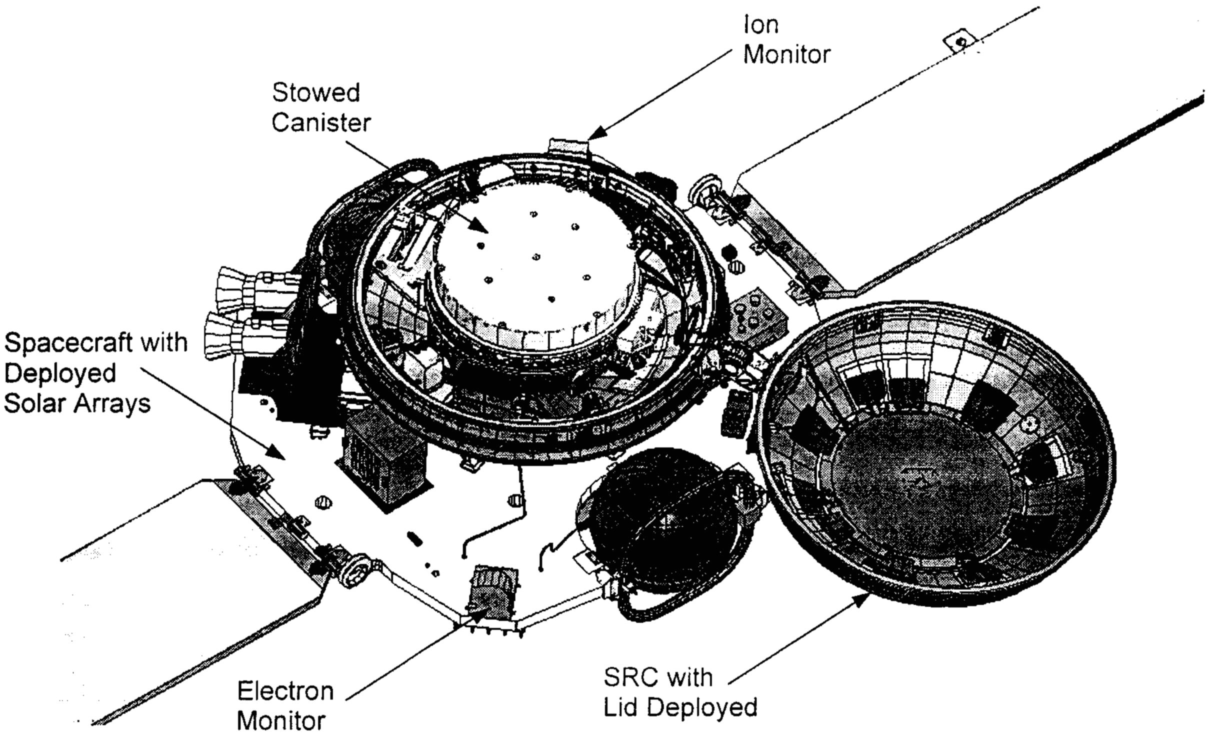


Figure 1. The Genesis payload integrated with the SRC and the spacecraft

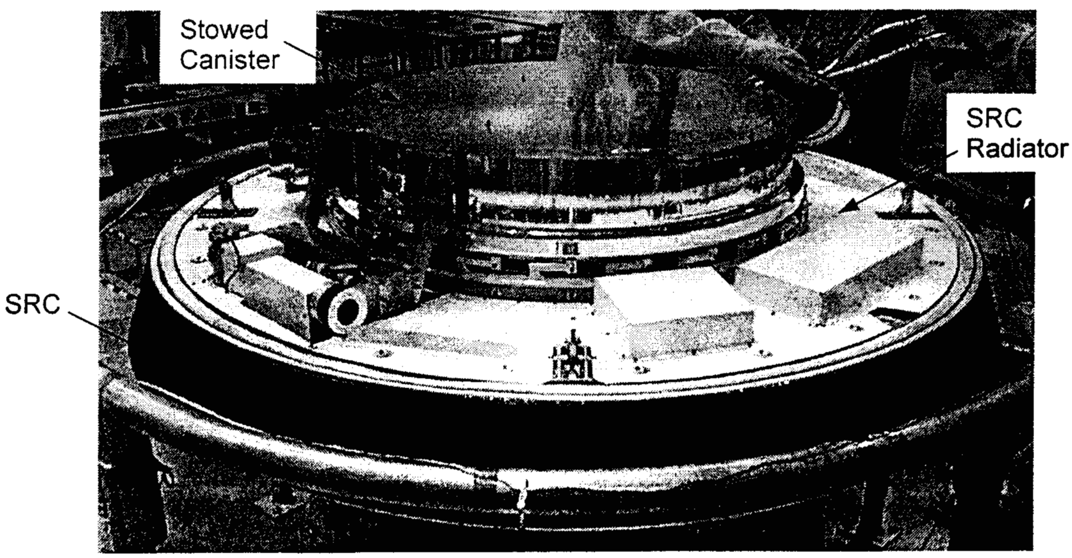


Figure 2. The Engineering Model canister integrated with the SRC

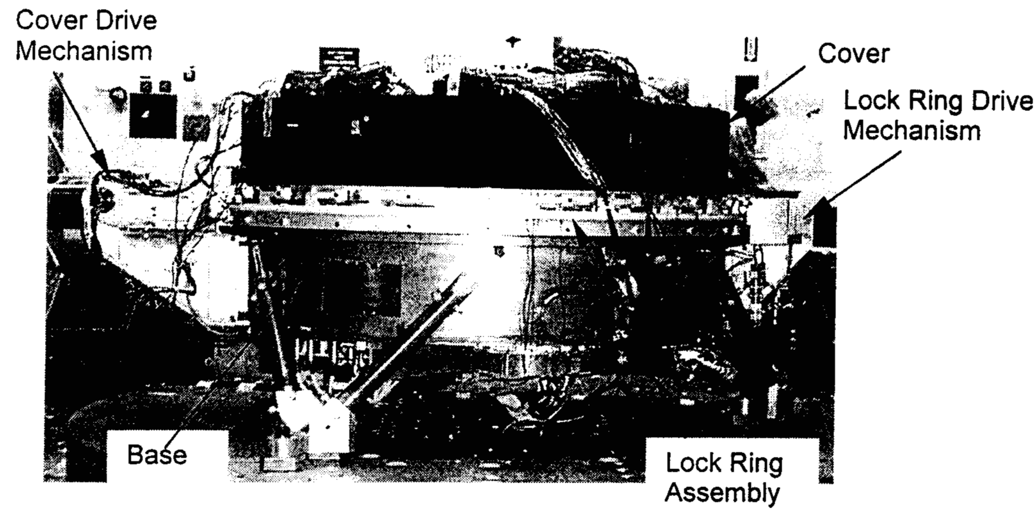


Figure 3. The Engineering Model integrated canister in the closed configuration is mounted on its vibration test fixture.

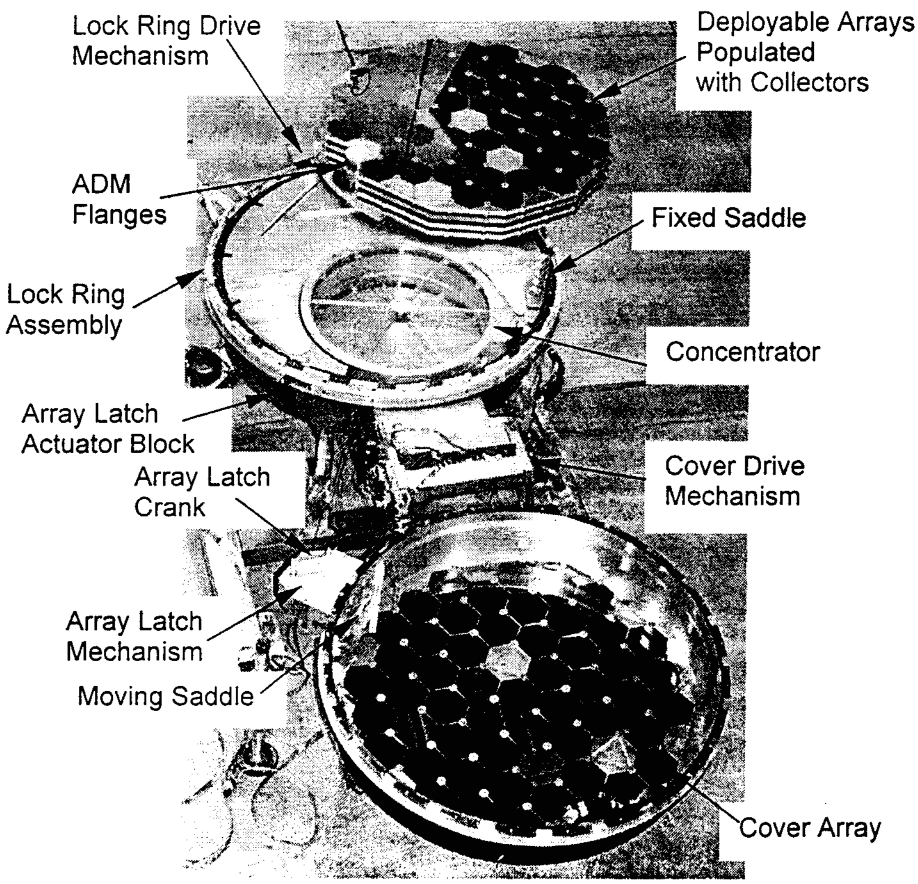


Figure 4. The Engineering Model integrated canister is shown in the open configuration.

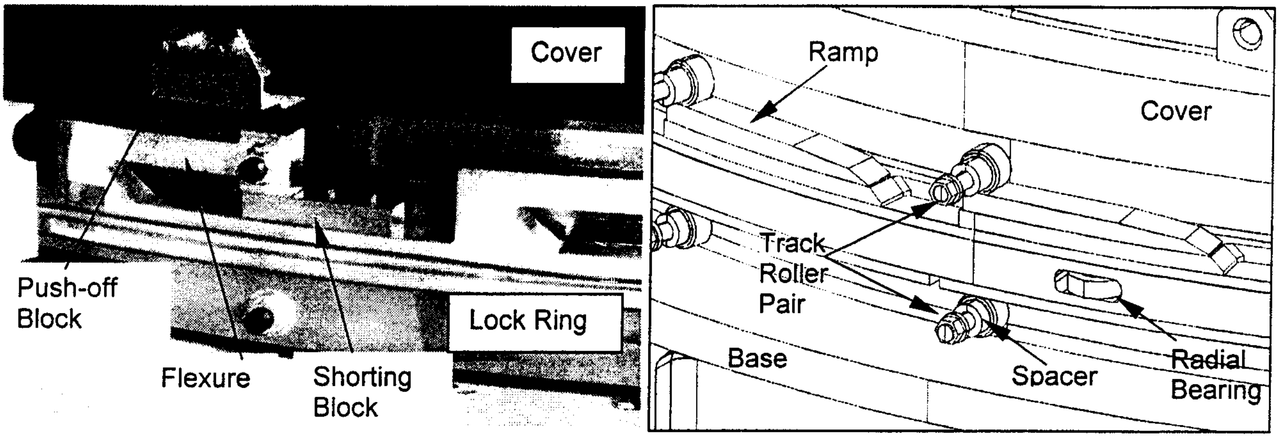


Figure 5a and 5b. A detailed view of the Lock Ring Assembly is shown. The figure on the right has the Lock Ring removed for clarity.

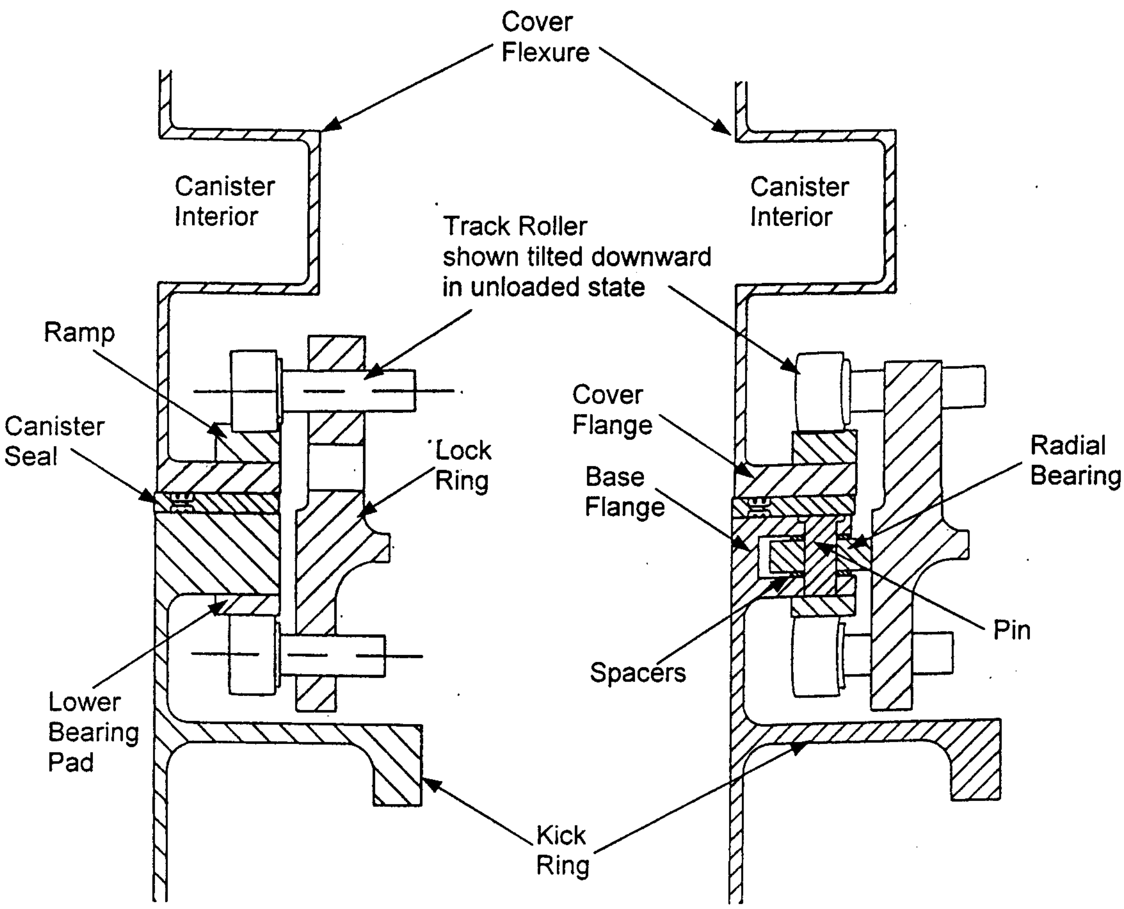


Figure 6a and 6b. Lock Ring Assembly sections through the track rollers in the left view and through the radial bearing in the right view

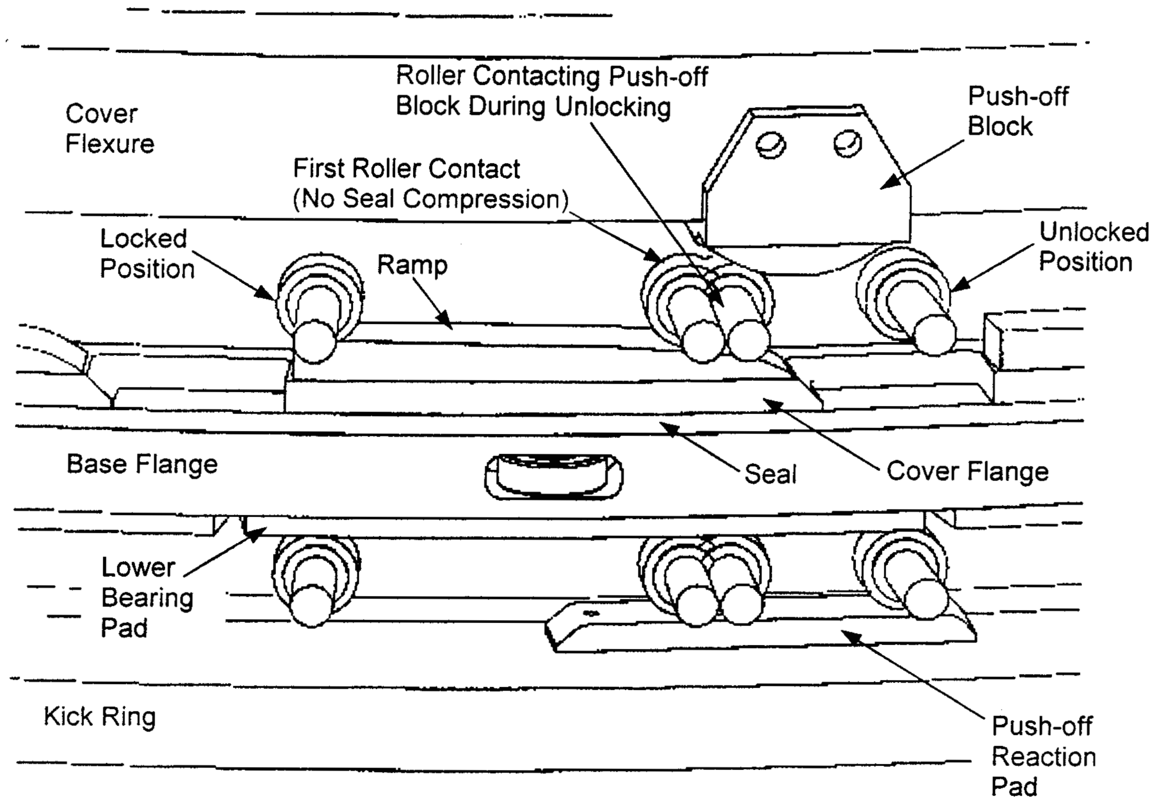


Figure 7. Lock Ring Assembly operation

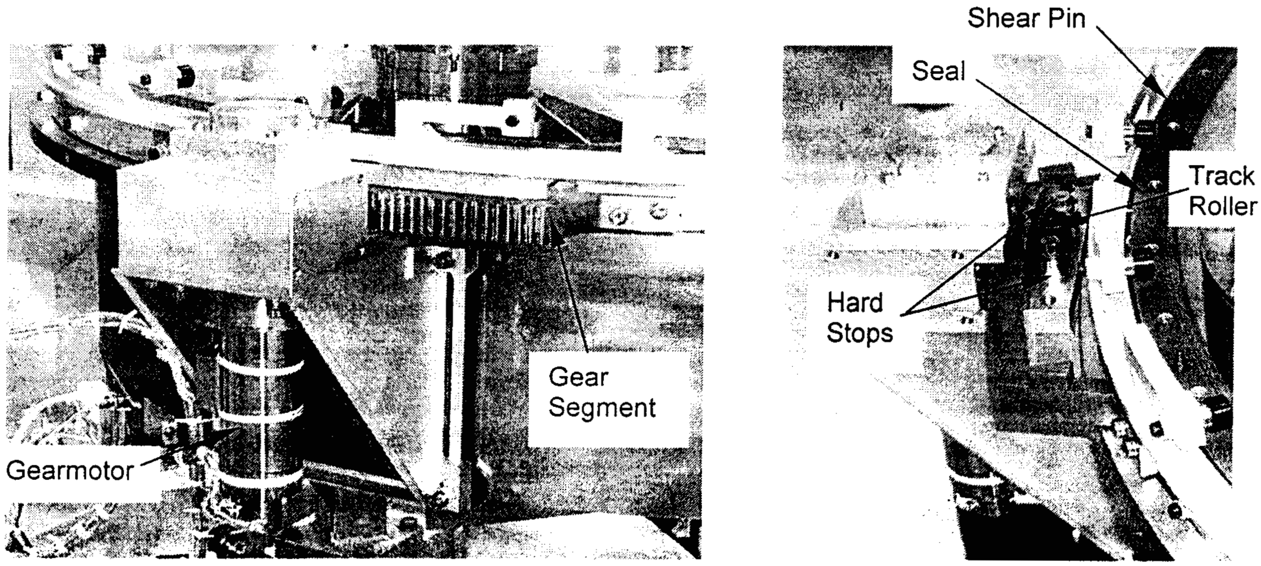


Figure 8a and 8b. The Lock Ring Drive Mechanism uses a pinion and sector geartrain to move the Lock Ring to its locked and unlocked positions.

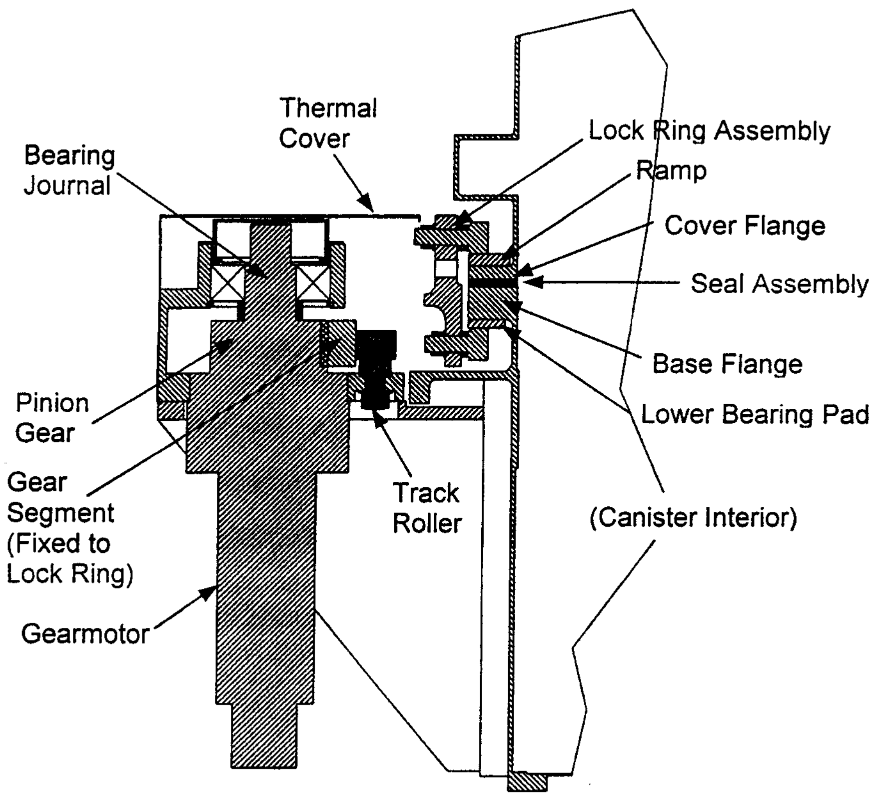


Figure 9. Lock Ring Drive Mechanism cross-section

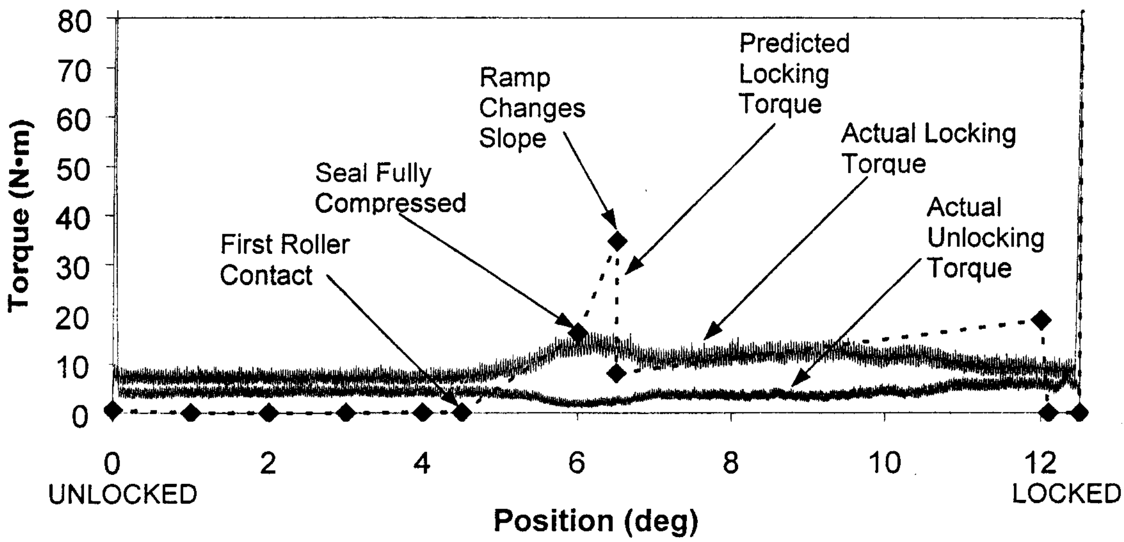
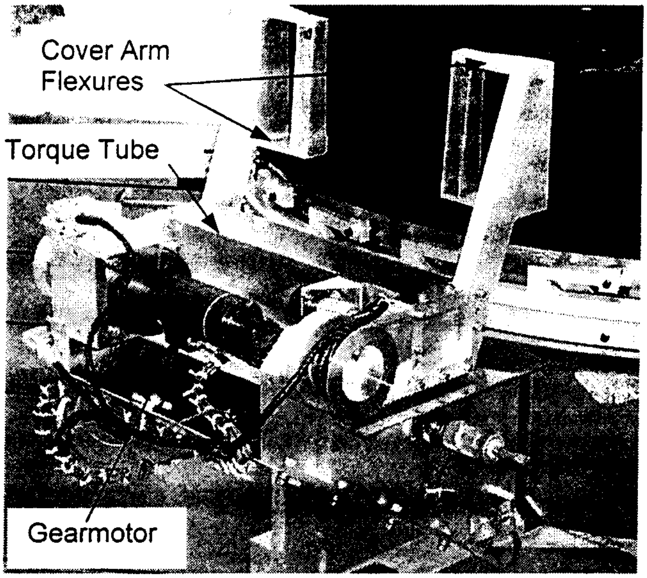


Figure 10. Lock Ring Mechanism operation



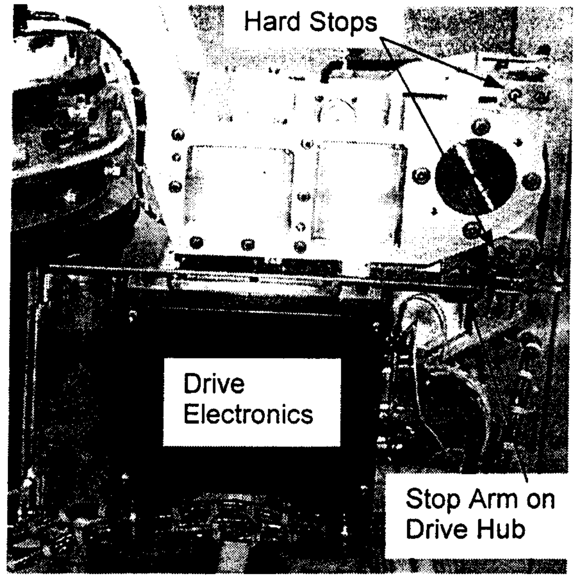


Figure 11a and 11b. The Cover Drive Mechanism opens and closes the canister cover.

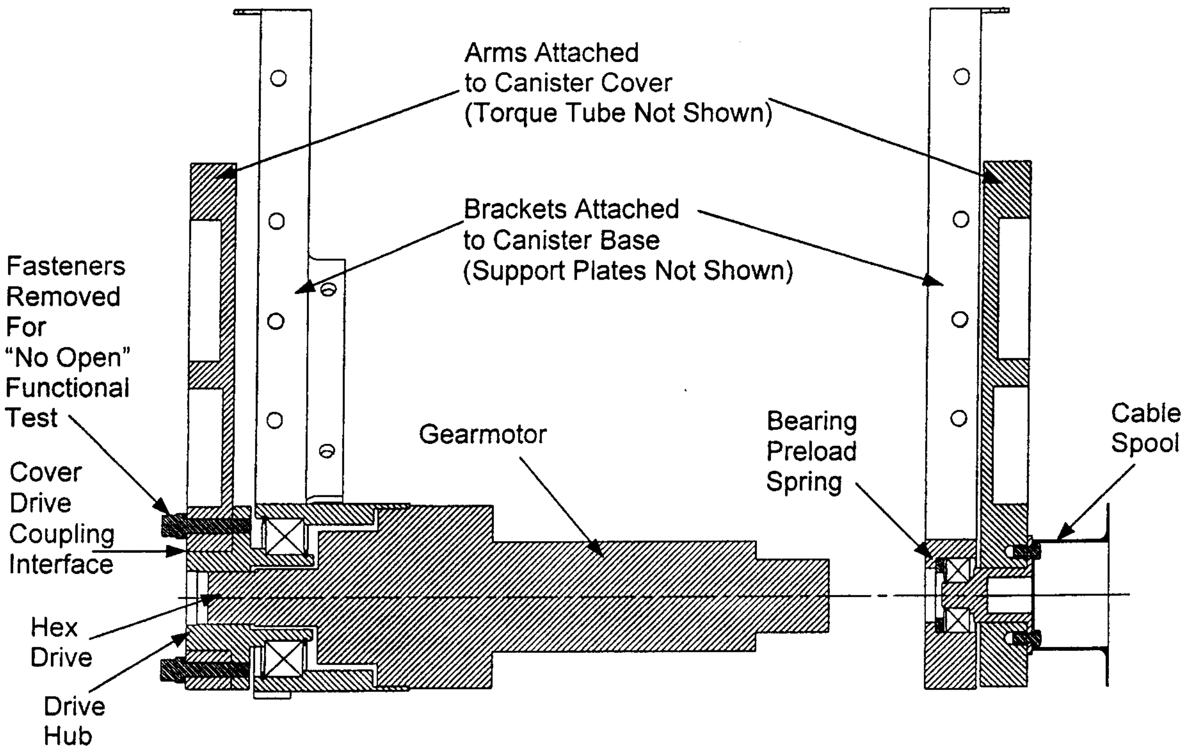


Figure 12. The Cover Drive Mechanism cross-section

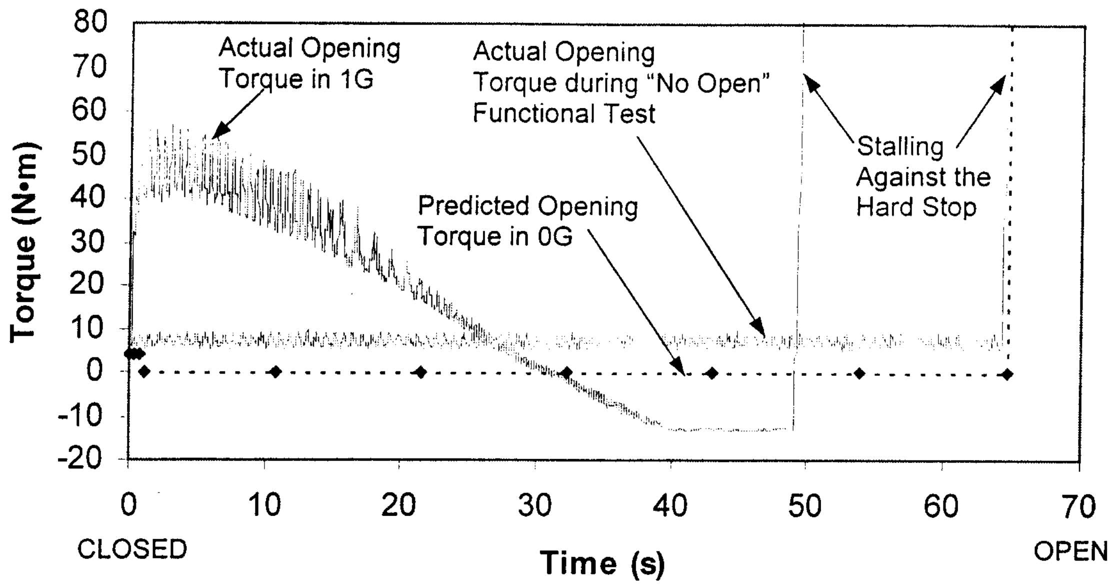


Figure 13. Cover Drive Mechanism operation

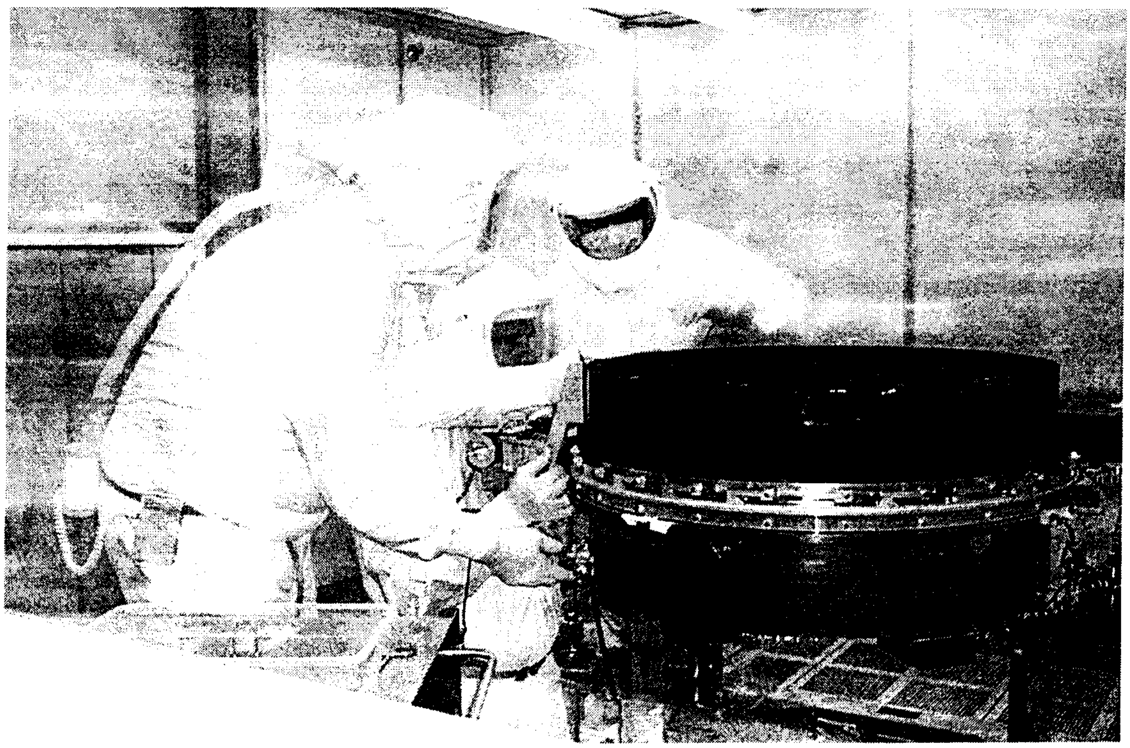


Figure 14. The Cover Drive Mechanism is reinstalled in the JSC Class 10 cleanroom after cleaning.